

# Predicting Resource Needs for Multiple and Mass Casualty Events in Combat: Lessons Learned From Combat Support Hospital Experience in Operation Iraqi Freedom

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**Objective:** We hypothesized that the number of evacuated casualties from a combat-related multiple casualty event provides an initial baseline estimate of the number of blood products required for the event.

**Methods:** A retrospective review of combat support hospitals' experiences in Operation Iraqi Freedom was performed, (from December 2003 to December 2004). Identified multiple casualty events were analyzed for mechanisms of injury, total number of patients arriving to the combat support hospitals, average injury severity score, operative interventions, blood product requirements, and short-term outcomes (24-hour mortality). Selected events

in which the Packed cells per Patient Index (PPI) was greater than a SD away from the mean were analyzed further regarding the casualties' injuries, the triage decisions during the event, operations, and patient outcomes.

**Results:** Of 367 days and 3,533 casualties, multiple or mass casualty events were identified on 26 days, accounting for 18% of casualties treated for the year. Twenty-two percent of all evacuated casualties from a multiple casualty event required transfusion and 4.2% required massive transfusion. Patients injured by discrete explosion-related events had an increased incidence of massive transfusion compared with patients injured from fire-

ights, 9.6% versus 4%, respectively, ( $p < 0.05$ ). The average number of RBC units (packed red blood cells units + fresh whole blood units) per patient (PPI) for these events was  $1.4 (\pm 0.8)$ . Review of casualty events where the PPI was higher revealed either potential triage or treatment errors.

**Conclusion:** Baseline blood product requirements for a multiple or mass casualty combat-related event can be estimated from the number of evacuated casualties involved.

**Key Words:** Military surgery, Mass casualties, Multiple casualties, Damage control resuscitation, Combat, Trauma, War.

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In modern combat, US medical facilities are routinely able to respond to multiple casualty events due to their ample infrastructure and capabilities. Uncommonly, because of the size or location of a mass casualty event, treatment requirements for the number of critically injured patients exceed local medical capabilities. Despite the infrequency of patient load exceeding local capabilities to simultaneously resuscitate all mass casualty patients, these events do occur in greater frequency in combat than in civilian settings. With regard to the wars in Iraq and Afghanistan, many articles have been written about the injuries affecting individual casualties and the devices, medications, processes, strategies,

and systems used to treat these casualties.<sup>1–21</sup> Relatively fewer articles have been written, however, directly addressing the management and resource utilization required for groups of simultaneous casualties as they occur in multiple and mass casualty events. To date, no data linking casualty loads to outcomes have been published. Such analyses are necessary for performance improvement, particularly regarding placement of surgical assets, medical regulation, and prediction of resource needs.

Analysis of combat casualties from Iraq and Afghanistan demonstrates that approximately 20% of casualties will require blood transfusion and 7% will require massive transfusion ( $>10$  units of red blood cells in 24 hours).<sup>4,10,14,22,23</sup> Whether the percentages of casualties requiring transfusion or massive transfusion from both multiple and mass casualty incidents (MCI) follow roughly the same distribution because the entire population of casualties is unknown. The ability to predict blood product resource needs based on the number of casualties generated by a MCI was described by Soffer et al.<sup>24</sup> in their analysis of blood product utilization after terrorist attacks in Israel. These researchers created a novel predictive index, the Packed cells per Patient Index (PPI). On analysis of 18 consecutive terrorist attacks, Soffer et al. found that the number of packed red blood cells (PRBC) units transfused per patient was related to incident size, with smaller incidents ( $<25$  evacuated casualties) having a PPI of 0.7 and larger

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incidents having a PPI of 1.5. Half of the units of PRBCs were required in the first 2 hours after the incident. An initial analysis of data from a single combat support hospitals (CSH) data supported this concept.<sup>25</sup>

We sought to describe the spectrum of injury for multiple and mass casualty events and to validate this basic predictive index by applying Soffer's technique to MCI during combat operations in Iraq. Creation of a reliable baseline prediction of blood product requirements for a multiple or mass casualty may assist medical regulators in determining how to best distribute patients to various deployed surgical assets and initiate resupply channels to ready more blood product resources.

## METHODS

We performed an IRB-approved retrospective review of 3,533 trauma patients treated at CSH in Iraq over a 367-day period from December 2003 to December 2004. Aside from lack of cardio-pulmonary bypass capability, dedicated angiography, magnetic resonance imaging, and robust holding and rehabilitation facilities, the modern combat support hospital can be augmented to approach capabilities of a civilian level I trauma center for the initial care of injured. The particular CSH in this study had 12 emergency department resuscitation bays, five operating room tables, one 8-slice CT scan, a range of four to eight general surgeons, two to three orthopedic surgeons, two neurosurgeons, two oromaxillofacial surgeons, one urologist, and intermittent vascular and cardiothoracic surgery availability. The primary sources of data were from a single CSH colocated in Baghdad and Balad. Included in the analysis were data on 91 patients from another combat support hospital (located in Mosul) regarding a single large mass casualty event that occurred during the same time period. To identify MCIs from the CSH database, we first calculated the mean and SD for the number of patients treated per day at the CSH for the entire year. Any date on which the number of casualties treated was one SD or more over the mean was analyzed. The Department of Defense website news archives, public news archives, and internet searches were performed for each of those dates, and casualty mechanisms as recorded in these news reports were compared with patients treated at the CSH. The individual casualties for each of these days were analyzed, and any casualties who were clearly not involved in the primary event(s) were excluded. These were primarily patients with mechanisms that were obviously not related to the event (e.g., motor vehicle crashes, falls). Dates where there were two or three temporally related events (particularly firefights), or in which the author's personal records revealed an MCI were included. The primary CSH involved was concurrently located at two locations, which received the majority of combat casualties in the theater.

Patients identified from MCI were analyzed for primary mechanism of injury, total number of patients arriving to the CSH, injury severity score (ISS), operative interventions, 24-hour blood product requirements, and short term outcomes (24-hour mortality). The ISS was calculated by trained

staff at the US Army Institute of Surgical Research according to methods described by the Association for the Advancement of Automotive Medicine Abbreviated Injury Scale, 1998 Revision.<sup>26</sup> Patients who were dead on arrival to the CSH were included in the analysis based on the assumption that they were alive at the time of evacuation and hence, were triaged at the scene to have potentially survivable injuries and intent to treat. The ISS assigned to patients that were dead on arrival were based on available clinical data and were not simply assigned a maximum ISS of 75. Our database did not consistently record arrival times to the CSH, and therefore these were not included in the analysis. Total RBCs were defined as PRBC + fresh whole blood (FWB). We chose to use the term "Packed cells per Patient Index" (PPI) to be consistent with the report by Soffer et al.,<sup>24</sup> although in fact our index factored both PRBC and FWB units. The mean and SD for PPI were calculated for all MCI. Selected events in which the PPI was greater than a SD away from the mean PPI were analyzed further regarding the casualties' injuries, the triage decisions during the event, operations, and patient outcomes. In several cases, providers directly involved in the treatment of casualties during these events were interviewed to confirm nature of the event, number of casualties, injuries, triage decisions, and problems involved with the conduct of the multiple or mass casualty treatment.

Descriptive statistics of mean (SD) and percentages were used to present the results.  $\chi^2$  Test or Fisher's exact test (where appropriate) were used to analyze categorical data and student's *t* test was used to compare continuous variables. Spearman's rho correlation was used to correlate number of patients per incident with number of total RBCs. SPSS version 14.0 was utilized for statistical analysis.

## RESULTS

The mean ( $\pm$ SD) number of patients treated per day at the CSH was  $9.4 \pm 6.7$ . Hence, a cutoff of 16 patients or more was used to retrospectively analyze for multiple or mass casualty events. In all, on 49 (13%) out of the 367 days in the time period 16 or more patients were treated at the CSH (range 16–45). Incident review from search of official to civilian news reports identified 25 days in which a mass casualty event occurred. Single large attacks accounted for 16 of these days and two to three moderate-sized, temporally related events occurred on the other 9 days. Although many smaller multiple casualty events occurred on the remaining 24 days, the casualties clearly occurred over the course of the day from multiple different and smaller incidents and so were excluded from analysis. Including the mass casualty event from the CSH in Mosul, a total of 26 events were identified. The mean number of patients from the MCI treated on these 26 days was 24 (range 9–91). MCI occurred in 26 of 367 days (7.1%) during the time period of the study. 618 casualties or 18% of all patient admissions occurred during MCI.

**Table 1** Age, Arrival Physiologic Data, and ISS for All Patients by Mechanism

	Explosion	Gunshot Wound
Age	27 ± 9	29 ± 10
SBP	126 ± 20	123 ± 22
DBP	69 ± 29	67 ± 15
HR	91 ± 21	94 ± 23
Temp	98.0 ± 1.8	97.8 ± 1.6
GCS	14	14
Hematocrit	38.2 ± 7	36.6 ± 7
pH	7.32 ± 0.12*	7.29 ± 0.13*
Base deficit	3.5 ± 5.4†	5 ± 5.3†
ISS	9.8 ± 12‡	8.1 ± 8‡

\*  $p = 0.041$ , †  $p = 0.043$ , ‡  $p = 0.047$ .

## Mechanism

Ten (38%) of the casualty-generating events were from mortar attacks, 8 (31%) occurred from improvised explosive device (IED), and 8 (31%) occurred from mixed-mechanism (explosions and gunshot wound) firefights. The primary mechanism of injury for the majority of casualties (73%) was explosion, with the remaining 27% of casualties injured by gunshot wound. The mean ISS for casualties who were injured in explosive incidents (improvised explosives, rocket, or mortar attacks) was higher than those casualties injured in firefights ( $10.4 \pm 4$  vs.  $7.8 \pm 2$ ,  $p = 0.041$ ).

## Demographics, Arrival Physiology, and Injury Severity

The majority of casualties (66%) were US soldiers or civilians and male (98%). Age, arrival physiologic data, and ISS for all 618 patients are displayed in Table 1. There were no significant differences noted based on mechanism of injury aside from a slightly lower pH ( $7.29$  vs.  $7.32$ ,  $p < 0.05$ ), slightly lower base deficit ( $-5$  vs.  $-3.5$ ,  $p < 0.05$ ), and lower ISS ( $8.1$  vs.  $9.8$ ,  $p < 0.05$ ) in patients who suffered gunshot wound mechanism compared with explosion.

## Operations

Of all evacuated patients (including those dead on arrival), data on therapies provided are available in 539 patients. A total of 415 of these patients (77%) required operation. The most common primary operation required was irrigation and debridement of wound(s), required in 168 of 539 (27%) of evacuated patients and accounting for 168 of 415 (41%) of all primary operative procedures performed. The second most common primary operation was laparotomy, required in 76 of 539 (14%) of all evacuated patients and 76 of 415 (18%) of all patients requiring operation. All the multiple or mass casualty incidents required laparotomies to be performed, with a mean and median of three and two laparotomies per incident (range 1–12). Numbers of different primary operations required, their percentage of all operations, and their percentage of all evacuated patients is listed in Table 2. Secondary operations were not included to simplify analysis.

**Table 2** Primary Operations in Order of Decreasing Frequency

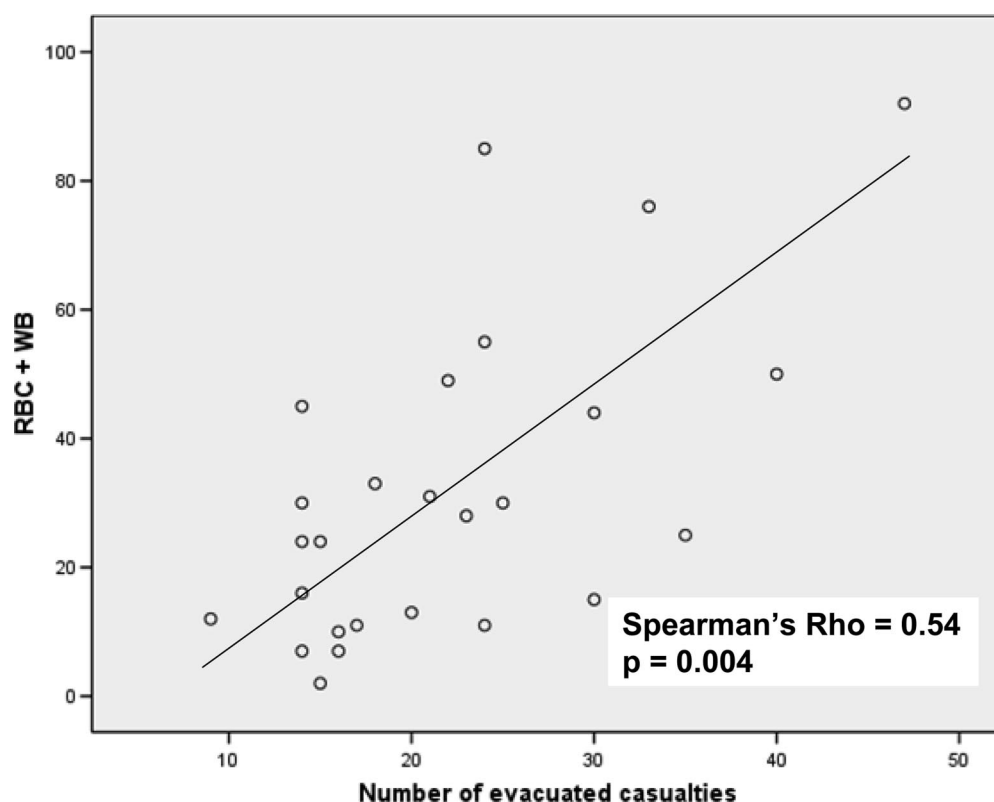
Primary Operation	Percentage of All Operations (n = 415)	Percentage of All Patients (n = 539)
Irrigation/debridement of wounds	41.1%	31.0%
Laparotomy	17.6%	14.1%
Skeletal fixation	10.6%	8.5%
OMFS/ocular procedures	8.3%	6.7%
Craniotomy	6.5%	5.2%
Vascular exploration/repair	5.3%	4.3%
Amputation	4.9%	3.9%
Thoracotomy	1.6%	1.3%
Neck exploration	1.4%	1.1%
Treatment of external GU injury	0.7%	0.6%

## Transfusions

A total of 767 PRBC units, 58 FWB units, and 196 fresh frozen plasma units (FFP) were transfused in 135 patients (22%). The mean RBCs transfused for any injured patient requiring blood was 6.3 units (range 1–46). The FFP:RBC ratio for all transfused patients was 1:4. Five packs of cryoprecipitate were transfused in only a single casualty, so this product was excluded from further analysis. Massive transfusion ( $>10$  units RBC  $\pm$  FWB) was required in 26 patients (4.2%), and at least one patient required massive transfusion in 21 (81%) of the incidents. For patients that received massive transfusion, the mean number of RBCs received was  $18.5 \pm 9.7$  units. The 26 patients receiving massive transfusion received a total of 410 PRBC, 113 FFP, and 51 FWB, accounting for 56% of all products transfused to all MCI patients. The FFP:RBC ratio for massively transfused patients was 1:3.4 (range 1:1.4–0:18).

Casualties generated from a discrete single attack ( $n = 17$ ) had twice the incidence of patients requiring massive transfusion (9.4% vs. 4.6%,  $p = 0.008$ ), higher PPI (2.0 vs. 1.1,  $p = 0.014$ ), and a trend toward higher ISS (12 vs. 8.5,  $p = 0.098$ ), than incidents involving multiple attacks or mixed mechanisms ( $n = 9$ ). The mean RBCs transfused for patients with injuries of moderate severity (ISS 16–24) was  $2.9 \pm 3.6$  units. The mean RBCs for patients with severe injury (ISS  $>25$ ) was  $6.7 \pm 10.1$  units.

Spearman's rho revealed correlation between the number of patients per incident and number of PRBC + FWB units transfused for that incident ( $r = 0.54$ ,  $p = 0.004$ ). The plot of number of patients versus units transfused per incident is displayed in Figure 1. The average PPI for all casualties was  $1.4 \pm 0.8$  (range 0.13–3.54). No significant differences were noted in the PPI based on type of incident (explosion vs. firefight), or the number of evacuated casualties ( $n < 25$ ,  $n \geq 25$ ).



**Fig. 1.** Plot of number of evacuated casualties versus number of blood product (PRBC + FWB) transfused per incident.

## Deaths

Deaths occurred in 85% of incidents with an average of three deaths per incident (range 0–22). Seventy-four (12%) casualties in all died. Fifty (68%) of these patients were dead on arrival to the CSH. Of the remaining 24 casualties who arrived alive at the CSH, 12 (50%) died of wounds to the head or brain; 8 (33%) died of hemorrhage within the first 24 hours; and 4 (17%) died >24 hours after admission of Multi-Organ Failure (MOF) or sepsis. On univariate analysis, there was no difference in the rate of death among different mechanisms of injury or different nationalities.

## Analysis of Specific Incidents—Low PPI

### *Incident 1: Insurgent Assault on Coalition-Fixed Position*

The first incident with a low PPI (0.50) was an insurgent assault on a Coalition forces position. Thirty casualties were evacuated from this event, although the ongoing insurgent assault was reported to have hindered evacuation of casualties. In this case, 5 (17%) of the evacuated casualties were dead on arrival to the CSH. Although specific data regarding prehospital injury times, treatments, and evacuation is not available, it is documented that one of the patients declared dead on arrival (DOA) had a proximal lower extremity amputation and contralateral vascular injury, loss of pulse enroute to CSH, and had cardiopulmonary resuscitative measures initiated on the helicopter. Three of the other declared DOA patients had penetrating abdominal wounds, one of whom had a damage control proce-

dures and massive transfusion (11 units PRBCs only) at a level II facility. The last patient declared DOA had a penetrating intracranial injury. Of the surviving patients, 60% required operation, which consisted of one laparotomy, one thoracotomy, one craniotomy, one neck exploration, two skeletal fixations, ten wound debridements, and one exploration of an external genitourinary injury. None of these patients required more than four units of PRBCs.

### *Incident 2: Improvised Explosion Hits US Soldiers*

This attack generated 15 casualties, six of whom had burns as a secondary mechanism. All patients were US soldiers, and all were recorded as wearing full body armor. Four of these patients had prehospital times recorded; the average prehospital time for these patients was 156 minutes. There were no prehospital or inhospital deaths in this group. The mean ISS for this group was 7. Eight patients (58%) required operation: one laparotomy, one craniotomy, two skeletal fixations, two wound debridements, and two OMFS or ocular procedures. This was the lowest percentage of patients requiring operation for the incidents analyzed. One patient required two units of blood, for a PPI of only 0.13.

## Analysis of Specific Incidents—High PPI

### *Incident 3: Rocket Attack Near Forward Operating Base*

This attack resulted in 22 casualties, 17 of whom were evacuated to the closest CSH and five of whom were sent to





**Fig. 2.** Pattern of fragments striking concrete building from rocket attack near a forward operating base (Photo courtesy of Tommy A. Brown).

another CSH (data are available; see Fig. 2). Of these evacuated patients, two were declared DOA to the receiving CSH. Two additional casualties were dead on arrival to the closest CSH. The mean ISS for all casualties in this event was 23. A total of 76% of the patients required operative therapy. Six (27%) of the patients required laparotomy, three for intra-abdominal injuries; one patient required an ocular procedure, one patient required an amputation, and eight patients required wound debridements. Interviews with an involved provider revealed that a staff surgeon assigned to a patient with an abdominal injury went to assist with another patient who had just arrived. The first patient subsequently manifested signs of shock and was taken to the OR where he died of hemorrhage from a large-liver laceration after receiving 13 units of PRBC, three units of FWB, and two units of FFP. The operating surgeon remarked that this patient's injuries were potentially survivable. The patient on whom the staff surgeon had been called to assist was made expectant after discovery of a massive intracranial injury, but this discovery was not made until the patient was in the OR. The PPI for this incident was 2.23.

#### **Incident 4: Vehicle-Borne Explosion and Concomitant Mortar Attack in Baghdad**

This incident resulted in 24 casualties evacuated to the CSH, 18 of who were foreign nationals. The PPI for this incident was 3.3, the highest PPI of the cohort of incidents. 95% of the casualties required operative therapy. Two of the treated patients received massive transfusion. Both of these patients underwent laparotomy for intra-abdominal injuries. One patient was transfused 27 PRBC, 4 FFP, and 2 FWB; the other was transfused 41 PRBC, 14 FFP, and 5 FWB. These patients' arrival pH or base deficits were 6.96 of 16 and 6.58 of 30, respectively. These two patients accounted for 89% of all the products transfused for this incident. Both patients

died in the OR from hemorrhage. Interview with an involved provider revealed that the surgeons involved in these cases did not stop transfusing products, despite evidence of refractory or irreversible shock. Furthermore, another patient with survivable injuries had delay in delivery of cross-matched blood products because of their use in one of the massive transfusion patients.

#### **Incident 5: Vehicle-Borne Explosion and Rocket Ambush**

This incident generated 14 casualties, 12 of whom were US soldiers. The PPI for this incident was 3.21, the second highest PPI for the cohort of incidents. 98% of these patients required operative therapy. One patient sustained multisystem injuries including a comminuted iliac wing fracture, a large gluteal wound, open lumbar fractures, an open humerus fracture, and bilateral severe lower extremity fractures and soft tissue injuries with a dysvascular right foot from lacerated anterior and posterior tibial arteries and associated fracture and soft tissue injury. The patient underwent damage control laparotomy and initial attempts to restore flow to the right foot with a tibial bypass, which required 6 hours and 45 minutes in the OR for his initial operation. The right-lower extremity bypass ultimately failed and his RLE required below-knee amputation. It was during his operations over the course of the first 24 hours of admission that he received 29 units PRBC, 11 FFP, and 10 of FWB, accounting for 89% of the blood products transfused in this incident. Review of the incident with involved providers revealed that the patient potentially would have benefited from early amputation, in light of his severity of injury and evidence of shock on arrival (SBP 48, pH 7.28).

#### **Analysis of Specific Incidents—PPI Near the Mean**

##### **Incident 6: Crowded Enclosed Facility Suicide Bombing**

This incident was a single explosion in a crowded enclosed facility. A total of 91 casualties were generated from this event. These casualties were taken to the local (nearby) CSH where triage was performed. Twenty-two patients were dead on arrival. An additional 22 patients were transferred by helicopter to another CSH. These patients typically had minor injuries or had isolated external hemorrhage sources controlled (e.g. tourniquets applied to amputated limbs), and were hemodynamically stable with normal mental status. Of the remaining 47 casualties, 12 (26%) required damage control laparotomy. The local CSH had two general surgeons who performed all the laparotomies. An obstetrician performed repeated triage to identify the next patient(s) for the OR. An orthopedic surgeon and a certified registered nurse anesthetist performed wound debridements and skeletal fixation in the ER trauma bays. A total of 80 units of PRBC, 12 units of FWB, and 8 units of FFP were transfused for a PPI of 1.0 for all casualties (including DOA) and a PPI of 2 for those treated at the local CSH. Resupply of blood products and other equipment and disposables to continue to treat patients was required about 2.5 hours into the MCI, but was



**Fig. 3.** The remains of a restaurant destroyed by a suicide bomb attack. This building was located a little over a block from the CSH that treated the majority of casualties.



**Fig. 4.** Smoke rising from site of a suicide bomb attack in an open-air market. The market was located approximately two blocks from the CSH that treated the majority of casualties. (Photograph taken by lead author).

completed without a cessation of treatment. All patients who survived to reach a CSH lived through evacuation out of theater.

#### **Incident 7: Baghdad Suicide Bombing**

This event featured two suicide bombers carrying satchels or bags of explosives who set themselves off within a minute of each other. One explosion occurred in a restaurant (Fig. 3), the other in an open-air market. Both explosions were approximately 1 to 2 blocks from a CSH (Fig. 4). Twenty living casualties began to arrive within 5 minutes of the explosions. Initial triage was performed at the hospital entrance by a senior cardiothoracic surgeon and a senior nursing supervisor. Six patients with minor injuries were

evacuated to another CSH about 30 minutes away. The number of dead from the incident could not be determined initially because of the severe destruction of many of the bodies. Ultimately, it was determined that five casualties had been killed. Of the 14 casualties treated at the local CSH, 77% required operative therapy, which consisted of one laparotomy, one craniotomy, six wound or burn debridements, and two ocular or OMFS procedures. One patient was diagnosed with probable blast-related pulmonary contusions, and the laparotomy patient had evidence of blast-related pulmonary contusion and blast injury to the jejunum and colon. A total of 16 units of PRBCs were transfused for a PPI of 1.1.

## **DISCUSSION**

This article is the first to analyze the spectrum of injury and blood product requirements from combat- or terrorist-related multiple or mass casualty incidents during Operation Iraqi Freedom. Our data demonstrate that the number of evacuated casualties (including those evacuated alive but arrive to the hospital dead) provides an initial baseline estimate for the number of PRBC required for a specific multiple or mass casualty incident. Casualties killed at the scene of the MCI should not be included in this estimation, as the numbers of dead will vary greatly based on the size and lethality of the event.<sup>27</sup> This baseline estimate is relevant, particularly given Soffer's finding that more than 50% of the transfused PRBCs for an MCI occurred in the first 2 hours.<sup>24</sup> The PPI estimate could potentially be used by medical regulators to decide to distribute casualties to multiple treatment facilities and by hospital logisticians to ensure local blood product resources meet anticipated needs.

Unlike the article by Soffer et al.,<sup>24</sup> we did not demonstrate a difference in PPI based on the number of casualties evacuated. However, we did demonstrate a higher PPI and greater numbers of patients requiring massive transfusion when the attack featured a discrete event, such as single-large blast, versus events where the casualties occurred from multiple smaller attacks or firefights. This finding has been demonstrated in another presented series of three large casualty events from Operation Iraqi Freedom, in which the PPI for all three events was 3.0 or greater (Lt. Col. Scott B. Davidson, Early Resource Utilization During Mass Casualty Events, unpublished data, presented at the San Antonio Trauma Symposium, August 2008).

Our data are also similar to the data by Soffer et al. both in terms of the actual values of PPI and in the variability in the PPI. This variability in PPI, which ranges from 0.13 to 3.54 in our study and 0 to 3.6 in the study by Soffer et al., has several possible explanations. Medical regulation may result in casualties with higher severity of injury being evacuated to the closest treatment facility, whereas less injured casualties are distributed elsewhere. This would potentially elevate the PPI for the main receiving hospital. In addition, great variability exists in the injuring mechanisms, personnel concentration and distances from the epicenter of an explosion,

personnel protective gear, and evacuation times. Soffer et al. identified most of these variables in his article, and these factors are not controllable by hospital personnel. In our review of specific events, we noted that triage and patient management decisions can also impact the PPI, and these factors are potentially controllable with increased training, streamlined triage, and mass casualty rehearsal drills.

Although there were five incidents where the PPI was less than a SD below the mean PPI, there was only one incident where the PPI was substantially less than 0.5. Of note, this one incident with the very low PPI (0.13) occurred in a group of US soldiers who were all wearing body armor and commonly had burns as a secondary mechanism. Although the data are not available, the lack of higher penetrating injury severity in this incident may have indicated that the soldiers were in vehicles and that the device may have been more incendiary than explosive in nature or both.

In at least three of the five incidents where the PPI was over a SD above the mean, we were able to demonstrate potential opportunities for improvement in either the triage process or patient management decisions which could in turn reduce unnecessary or futile blood product expenditure. We also noted that the FFP:RBC ratios for transfused and massively transfused patients from this cohort were 1:4 and 1:3.4, respectively. These ratios are lower than are currently practiced, which is an indication that this data were collected early in the war before FFP:RBC ratios of 1:1 had been recommended. Our data were collected in 2004, and the ALARACT recommending 1:1 resuscitation was published in 2006 by the US Army Surgeon General based on data by Borgman et al. Another possible explanation for the lower FFP:RBC ratios in this cohort is that presence of multiple critically injured casualties at once may result in dispersion of skilled providers, less efficient operations, and more liberal or less efficient use of blood products.

Further study on the use of plasma and platelet units per casualty in MCIs is required. Bulger's invited critique at the end of the article by Soffer et al. suggested that predictive indices for blood product requirements in mass casualty events should take into account plasma, platelet, and cryoprecipitate needs, particularly given the current recommendations to give thawed plasma early in the resuscitation of severely injured.<sup>24</sup> Our findings demonstrate that roughly 4% to 9% of patients in MCIs will require massive transfusion, and that 56% of the blood products transfused will be in the setting of massive transfusion. This closely matches the findings by Soffer et al. Hence, in addition to predicting PRBC needs, the PPI could be used to predict plasma needs and allow logisticians to prepare additional units of thawed plasma for early transfusion in arriving casualties.

The concept that not just the total number of casualties but the number of critically injured casualties arriving in short time periods and triage decisions may be the most decisive factors affecting available resources was discussed by Hirshberg et al.<sup>28</sup> Our data supports this concept, at least with

regard to blood product resources. Review of incidents with a high PPI also demonstrated that while the current numbers of deployed trauma providers generally provide adequate "surge" capacity for the majority of multiple casualty events, triage problems could still lead to unnecessary or futile resource expenditure.

Our data on average units transfused for injured patients are similar to other published reports. Rosenblatt et al.<sup>29</sup> demonstrated averages of 3.85 units transfused for moderately injured patients and 13.6 units for severely injured patients. Data from Israel demonstrated that moderately to severely injured casualties received on average 6.7 units of blood, a number strikingly similar to our findings.<sup>30</sup> The applicability of this data to modern civilian disaster planning remains to be determined.

Currently, planning is underway for disasters or terrorist attacks with the potential for thousands of casualties requiring transfusion. This planning includes proposals to augment local blood bank resources once local components are exhausted with FWB drives (Dr. Kathy Brinsfield, Medical Director, Public Health Preparedness and Homeland Security, Boston EMS and Boston Public Health Commission).<sup>31</sup> The challenges to overcome in dealing with events of this size are obvious. First, historically, no need for massive scale blood transfusions of more than 300 units has been reported for a single event.<sup>32</sup> The reasons for this may be that massive disasters have both high immediate lethality and such substantial local destruction that it disrupts the ability of rescue personnel to reach critically injured casualties in time to save them. The triage of casualties at the scene, which in the military is usually done by trained and experienced medics dealing with relatively small groups of casualties, may not be possible. Treatment areas are frequently overrun with minimally injured casualties, resulting in over-triage and engagement of providers.<sup>33</sup> Casualties with survivable injuries may die because of the inability of rescue teams to find and evacuate them in a timely fashion.

Hence, the use of the number of evacuated patients as a baseline estimate of blood product requirements requires skilled scene triage to minimize the transport of moribund or minimally injured casualties to the trauma center. Our data, which demonstrate that a majority of evacuated casualties required operation, suggests that this initial triage process was effective. The Emergency War Surgery Manual provides important guidelines for this process, with the emphasis that triage must occur at multiple levels of care and be repeated until all casualties are treated.<sup>34</sup> Our data revealed that there is opportunity to improve on the in-hospital triage process, which should be considered for future training initiatives. Surgeons must be willing to retriage patients in the operating room as expectant based on injuries identified, blood products required, physiologic status of patient, and number of other casualties requiring operation.

Several limitations to our data should be noted. First, the data are retrospective and key prehospital elements, such as



incident descriptions, evacuation times, and triage categories are missing. Long-term follow-up is not immediately available for the majority of patients. Because arrival times were not reliably recorded, some of the incidents analyzed may in fact be spread over many hours and therefore not represent true multiple or mass casualty events. In-hospital data about triage decisions and problems with resources are also not available for all events. The triage decisions described in the discussion of the specific incidents had to be gained from interview of providers well after the fact, and may be subject of memory error. Nevertheless, the findings are similar to the Israeli experience with resource needs in MCI as described in a report by Soffer et al.<sup>24</sup> and other reports on blood product utilization in MCI.<sup>29,30</sup>

Past and current counter-insurgency combat engagements in Iraq have featured attacks on coalition formations of vehicles or convoys, either by explosion, ambush, or both; indirect fire or suicide bomber attacks on coalition fixed facilities; and direct fire engagements with enemy combatants ("fire-fights") where both small arms and explosive grenades are used. In all cases, the sustaining of multiple casualties is common, and in fact the single isolated casualty arriving to a busy CSH is a relative rarity. The incidence of true mass casualty events, where the number of critically injured casualties overwhelms the capacity of the medical infrastructure, is considered relatively low in the current theater. Nevertheless, these events occur with greater frequency than in civilian settings, and so the opportunity exists to study the resources required in an effort to create predictive models. Currently, with regard to the wars in Afghanistan and Iraq, no data analyzing casualty load per unit time and outcomes has been published, and this should be a focus point for future research efforts.

In summary, the current military trauma systems in Iraq and Afghanistan are effective at dealing with both routine multiple casualty events and the less common mass casualty event. Analysis of multiple and mass casualty events from current conflicts can provide critical lessons learned regarding triage and resource utilization, which can potentially be applied to other conflicts or civilian multiple or mass casualty events. Although the findings of this study regarding blood product utilization may not be directly applicable to catastrophic, national-level events, the consistency of the findings with the noncombat Israeli experience and across a wide range of smaller multiple or mass casualty explosion-related events is striking. Hence, for such events, the number of casualties triaged and evacuated as needing hospital care may provide an initial *baseline* prediction of blood product needs and percentages of patients who will require transfusion and massive transfusion. Critical to this estimation is effective triage at all levels. This in turn can help determine distribution of casualties among medical treatment facilities and allow for activation of additional blood resources, such as notification of more distant blood banks or initiation of FWB drives.

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